Effect of Glazing Number on the Performance of a Solar Thermal Collector

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Abstract: ***In this research paper, an attempt has been made to come across the effect of multiple glazing covers on the efficiency of a solar thermal collector. This experimental investigation was carried out on an active solar energy demonstration system (ET 200), illuminated with a halogen lamp. Three commercial glass panes of 3 mm thickness, having the same dimensions as that of the apparatus glazing, were used. Tests were done with and without the added glass panes, at a fixed water flow rate of 5.8 l/h, taking the whole surface of the collector maintained at an horizontal position. Experiments were performed with two positions of the light meter. In one position, it was placed in the middle of the collector surface. While, in the other, the light meter was placed in the middle of the upper glass added. Double, triple and quadruple glazing, reduce the amount of heat absorbed by water by deceasing water temperature difference between the inlet and outlet of the absorber. Double glazing decreased the efficiency of the solar collector with 15%. This efficiency was decreased by 29,95% for triple glazing, and by 45,96% for quadruple glazing. The addition of glass panes above the collector surface, acts as a resistance to the spread of the energy transmitted by the halogen lamp, this effect reduces the performance of the solar collector instead of improving it, according to a linear equation with a high correlation coefficient.***

Keywords*:* flate plate solar collector, efficiency, double glazing, triple glazing, quadruple glazing.

1. Introduction

Massive exploitation of conventional energy continues to increase, during the twentieth century, which has the effect of depletion of conventional resources in energy. In addition, global warming is another consequence of the massive exploitation of hydrocarbons that produce large amounts of greenhouse gas emissions. For this purpose and to better safeguard the future of humanity, it is recommended to rationally use conventional energy and to develop renewable energy sources, which are inexhaustible and clean [1].

The sun can be classified as a very important source of energy. This energy can be used in several areas such as; drying agricultural products and wood, distillation of sea water, space heating and cooling, hot water production, producing electricity, solar refrigeration, etc [2], [3], [4]. Solar energy is the most important source of renewable energy in the globe.

One of the simplest and most direct applications of this clean and free energy is to convert solar radiation into heat. This conversion is accomplished using solar panels with the aim of heating water or /air for domestic and industrial applications [3]. Flat plate solar collectors constitute a subset of devices that convert solar energy into heat [4]. There is an increasing demand for the solar collectors, especially the flat plate collectors that can be deployed for duties such as domestic water heating.

Most solar water heating systems for buildings have two main parts: a solar collector and a storage tank. Solar collectors are the key component of solar-heating systems. They collect the sun's energy, transform its radiation into heat, and then transfer that heat to a fluid (usually water or air).

The traditional flat plate solar collector consists of essentially four major components fabricated as a 'sandwich'; the glazing, air gap and insulation layers act to prevent heat loss from the solar collector to the environment, while the absorber plate coupled with the heat transfer tubes actively remove heat from the solar collector for the desired application [4].

The glazing acts to prevent heat losses from the panel to the environment via convection and radiation. In fact, the incoming solar radiation (in the near infrared) is allowed to pass freely through the glazing, but that radiative thermal losses (in the far infrared) are blocked (green house effect).

The heat loss from the top of the glazing layer can also be reduced by using multiple glass layers [5]. This paper presents an experimental investigation about the effect of multiple glass covers on the performance of the ET 200 flat plate solar collector.

2. Experimental Setup

In this study, experiments were carried out on a fully functional demonstration model (ET 200) of a system for heating domestic water. This laboratory scale solar collector is illuminated with a halogen lamp as illustrated in Fig. 1. The solar system for heating domestic water consists of water storage tank (1), a flat plate solar collector (2), a high-power lamp (3) and a control and command cabinet (4).

Figure 1: Experimental device [6]

Solar collector is a planar collector with a single glazing pivoting around an axis; it allows an inclination angle from 0° to 60°.
The absorber, which is the central element of the collector, consists of three bands of 320x120 mm² each one. Heat removed from the absorber plate by means of a flow of water 'heat transfer fluid' through straight parallel pipes affixed to the back of the absorber plate, is transferred to water tank via the circulation of water inside a serpentine heat exchanger placed in the storage tank (see Fig. 2).

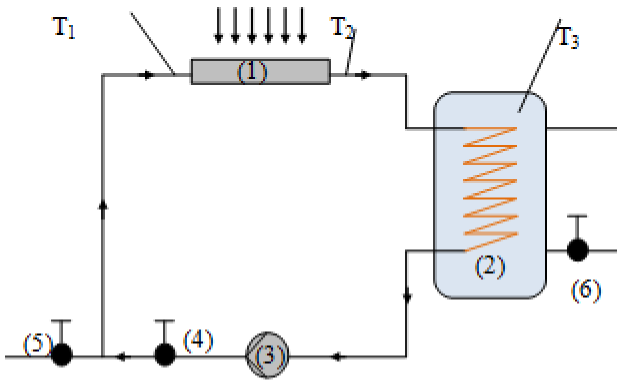

Figure 2: Schema of the solar demonstration system (1) collector, (2) tank, (3) circulation pump, (4) (5) (6) valves

Temperature measurements are performed by sensors PT 100 placed at the inlet T_1, at the outlet T_2 of the absorber and in the storage tank T_3 (see again Fig. 2).
A pump for circulating water is used by this laboratory system. The flow control is provided by a valve for regulating the volume flow located on the control and command cabinet.
Halogen lamp high power (max 1000 W) simulating natural sunlight is used in our study. Thus, the naturally incident solar radiation is replaced by the halogen lamp. Illuminance measurement is carried out with a heliometer.
The measures of water flow rate, temperature and illuminance are shown on the digital displays of the control and command cabinet (see Fig. 1).

3. Governing Equations

In a steady state, the energy balance of the collector area is given by the following equation [7]:

$$E = E_u + P \quad (1)$$

Where;
E : Incident solar flux received by the glass surface of the solar collector (W);
E_u : Useful flux, i.e. incident solar flux received by the fluid (water) (W);
P : Fluxes lost by convection and conduction towards the back of the collector and by convection, conduction and radiation forwards of the collector.

3.1 Incident solar flux

The power transmitted to the flat plate collector surface is captured directly by the light meter placed exactly in the middle of the collector surface under the lamp to obtain correct measured results. Its value (per meter squared) is read on the control and command cabinet. This value must be multiplied by a correction factor of 2.95 to get the real value [6], [8]. The incident solar flux relation is expressed by:

$$E = I \times S \quad (2)$$

With;
I : Illuminance, i.e. incident solar flux by glass surface (W/m²);
S : Exposed area to radiation (m²).

3.2 Useful flux received

The useful flux recovered by water is given by the following equation:

$$E_u = \dot{m} \times C_p \times (T_2 - T_1) \quad (3)$$

With;
$\dot{m}$: Water mass flow rate (kg/s), which is related to volumetric flow rate by the following relation:

$$\dot{m} = Q_V . \rho \quad (4)$$

Q_v : Volumetric flow rate (m^3/h);
ρ : Water density (kg/m^3);
C_p : Water specific heat;
T_2 : Absorber water outlet temperature;
T_1 : Absorber water inlet temperature.

3.3 Instantaneous solar collector efficiency

The instantaneous efficiency of a solar collector is defined as [7], [9]:

$$\eta = \frac{E_u}{E} \quad (5)$$

It presents the relationship between the useful flux received by water and the incident solar flux received by the glass surface of the solar collector. It can be simplified by the following equation:

$$\eta = \frac{\dot{m} \times C_p \times (T_2 - T_1)}{I \times S} \quad (6)$$

4. Effect of multiple glazing layers

To highlight the effect of double, triple and quadruple glazing, on the ET200 solar collector performance, experiments were carried out with a fixed water flow rate of 5.8 l/h, taking the whole surface of the collector (Stotal= 0.13838 m²) maintained at an horizontal position. For this purpose, three commercial glass panes of 3 mm thickness, having the same dimensions as that of the apparatus glazing were used. The emissivity of the glasses used is of 0.84. To evaluate the effect of double-glazing, tests were performed using only one commercial glass placed above the collector at a distance of 2 cm (see Fig. 3).

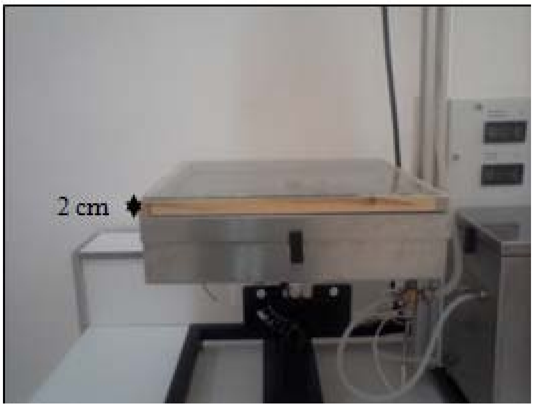

Figure 3: Solar collector with double glazing.

To evaluate the effect of triple-glazing, tests were performed using two commercial glasses separated by 2 cm, placed above the collector at a distance of 2 cm. To evaluate the effect of quadruple-glazing, tests were performed using three commercial glasses separated by 2 cm. The sandwich, thus formed, was placed above the collector at a distance of 2 cm. Tests were done, also, without the added glass panes i.e; with single glazing.

In order to determine the incident flux received by the collector surface and that received by the upper glass pane added, experiments were performed with two positions of the light sensor. In one position, it was placed in the middle of the collector surface. While, in the other, the light meter was placed in the middle of the upper glass added.

Each test lasted 150 minutes, and the absorber water inlet temperature T_1, the absorber water outlet temperature T_2 and the tank temperature T_3 were recorded every five (05) minutes. All tests were performed in laboratory at an ambient temperature of 23 ± 1°C.

5. Results and Discussions

5.1 Influence of multiple glass layers on temperature evolution

The halogen lamp radiation transmitted through the glazing propagates onto the absorber plate. Heat removed from the absorber plate by means of water flow results in change in water temperatures at the inlet and the outlet of the absorber.
The first interpretation of the collected temperatures led us to plot the evolution of the temperatures T_1, T_2 and T_3 over time. All graphs showing the evolution of the temperatures T_1, T_2 and T_3 versus time had the same appearance for all experiments done. Fig. 4 shows an illustrative example for a triple glazing.
As illustrated in Fig. 4 all temperatures T_1, T_2 and T_3, increase with time. Temperature T_2 is always higher than the other temperatures (T_1 and T_3); it presents the water temperature at the outlet of the absorber. Its value is the highest one due to heat water absorption occurred in the absorber. After water heated passage in the tank, heated water gives an amount of heat to cold water tank, as a consequence, temperature T_1 takes the lowest value, and water tank temperature (T_3) increases.

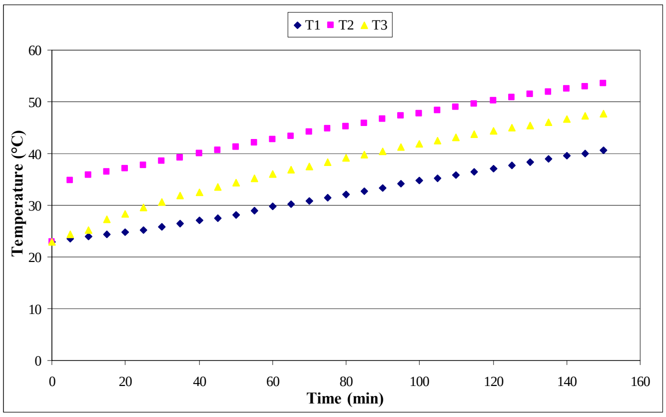

Figure 4: Temperatures T_1,T_2 and T_3 evolution over time for a triple glazing.

Thus, storage tank temperature takes the intermediate value between the lowest and highest temperatures (see Fig. 4).
Again, all graphs showing the evolution of the temperature difference (T_2-T_1) as a function of time for all experiments done, had the same appearance (see Fig. 5). As seen, temperature difference evolution can be divided into two phases: the first one called transitional phase from 0 to 30 minutes, is characterized by a non-linear increase of the temperature variation, followed by the stable phase, from 30 minutes until 150 minutes, where this difference takes almost a constant value. The time interval when the temperature difference, as a consequence, the efficiency of the collector, are time independent is called also steady state phase. This investigation was studied during the steady state phase i.e. beyond 30 minutes [6], [8].
As shown in Fig. 5 and according to "(3)," double, triple and quadruple glazing affect the amount of heat absorbed by water. In fact, double, triple and quadruple glazing, reduce the amount of heat absorbed by water by deceasing water

temperature difference between the inlet and outlet of the absorber.

As seen in Fig. 5, temperature difference (T_2-T_1) decreases, as we add glass panes. Adding commercial glass panes does not increase water temperature difference between the inlet and outlet of the absorber; as a consequence it doesn't improve the amount of heat absorbed by water. For example double glazing reduces the amount of heat absorbed by water by 9%.

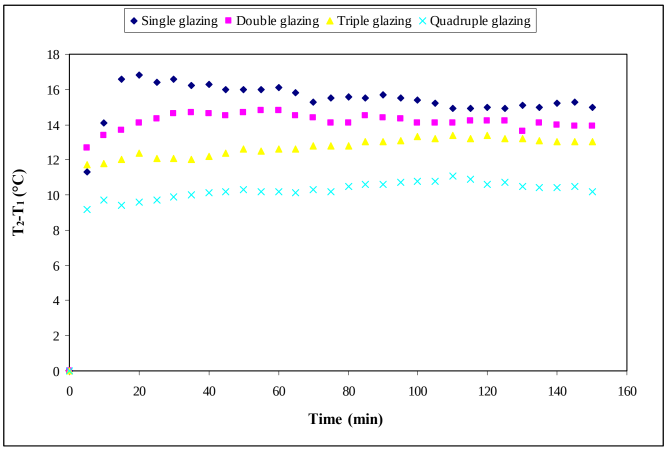

Figure 5: Temperature difference (T_2-T_1) evolution over time for single, double, triple and quadruple glazing.

Note that temperatures T_1, T_2 and T_3 were independent of the light meter position. We have plotted, also, the evolution of tank temperature T_3 versus time for single, double, triple and quadruple glazing (see Fig. 6). It seems that tank temperature is affected by the additional glass panes. In fact, storage tank temperature T_3 decreases, as we add glass panes. This result is in agreement with the temperature difference between the collector feed and return (T_2-T_1).

According to Fig. 6, it is clear that solar collector with single glazing heats better reservoir water compared with double, triple and quadruple glazing.

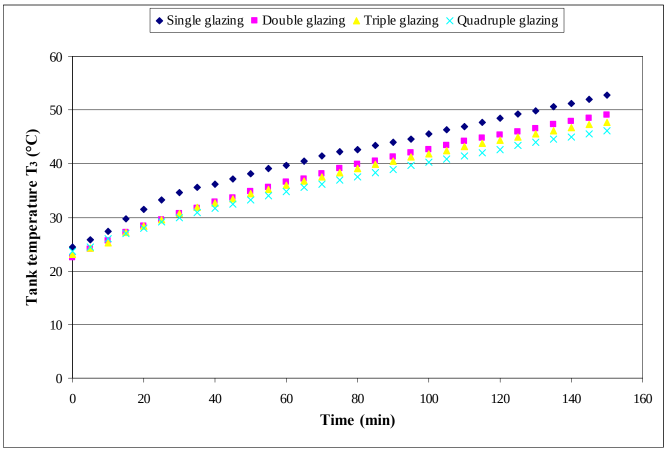

Figure 6: Effect of multiple glass layers on tank temperature evolution.

5.3 Effect of multiple glass layers on the evolution of the radiation intensity received by the collector surface and the upper glass added

As mentioned in a previous study [10], the correct position of the light meter when studying the effect of additional glass panes is to place it on the upper glass. The radiated energy received by the upper glass, increases with the number of glass panes added (see Fig. 7). In contrast, the power transmitted to the flat plate collector surface decreases with adding glass panes.

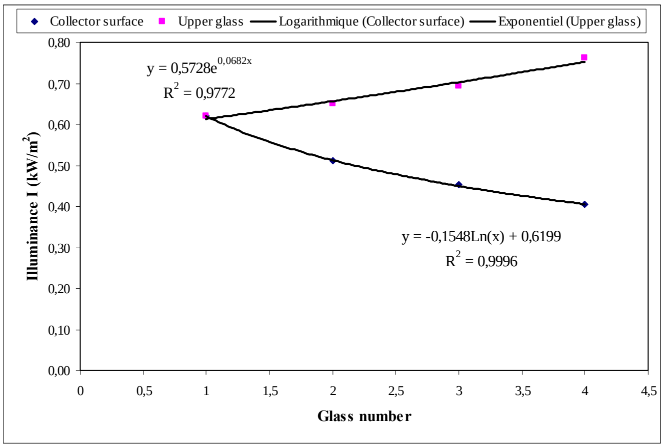

Figure 7: Evolution of the radiation intensity received by the collector surface and the upper glass added.

When adding glass panes, the upper pane approaches the halogen lamp. In other words the distance between the heat source 'halogen lamp' and the upper pane will be reduced which increases the energy received by the upper glass.

For example, in the case of double-glazing, the energy transmitted to the upper glass is higher than that received by the collector surface with simple glazing (see again Fig. 7).

For all experiments done with multiple glass covers, the energy received by the glass solar collector 'lower pane' is lower than that received by the upper glass (Fig. 7). Therefore, the sandwiches formed by glass-air-glass, for double glazing, glass-air-glass-air-glass, for triple glazing and glass-air-glass-air-glass-air-glass for quadruple glazing act as thermal insulators, due to the high thermal resistance of air (thermal conductivity of air λ= 0.026 $Wm^{-1}°C^{-1}$), being trapped between glass panes (see Fig. 3 for double glazing).

As a consequence, in our case, the thermal resistance of double glazing is lower than that of triple glazing and so on. From these results, the following mathematical relationship that connects the illuminance I to the number of glass panes (ng) added can be proposed as:
For the upper glass added:

$$I = 0,57 \exp(0,068 \times n_g) \quad (7)$$

This correlation has a determination coefficient (R^2) of 0.977.
For the glass collector surface:

$$I = -0{,}155\ \ln(n_g) + 0{,}62 \quad (8)$$

This correlation has a determination coefficient (R^2) of 0.99.
With;
I: Illuminance, i.e. incident solar flux by upper and lower glass surfaces respectively (W/m²);
n_g : Number of glass panes added.

The incident solar flux received by the upper glass increased, following an exponential relation, with the number of glass panes added. While, the incident solar flux received by the collector surface 'lower glass' decreased, following a logarithmic relation, with the number of glass panes added.
The results obtained in the preceding paragraph concerning the amount of heat absorbed by water in the collector are in agreement with those of the incident flux received by the collector surface.

5.3 Effect of multiple glass layers on the efficiency of the solar collector

The effect of adding additional glass panes on the efficiency of the solar collector is shown in Fig. 8.
The efficiency of the thermal solar collector without the added glass panes, 'single glazing' is also, presented in Fig. 8.

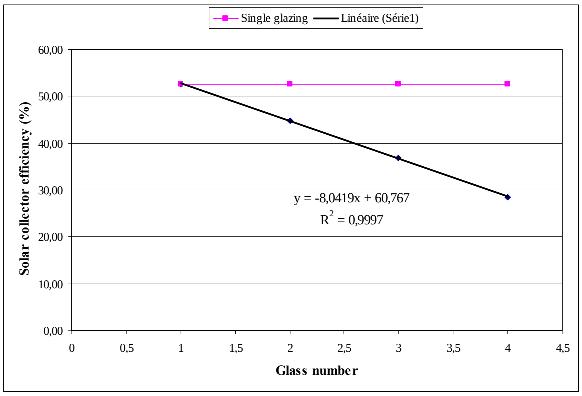

Figure 8: Effect of adding glass panes on the efficiency of the solar thermal collector.

As seen in Fig. 8, adding additional glass panes affect the performance of the solar collector, In deed, the efficiency of the apparatus decreases with adding glass panes. Double glazing doesn't improve the performance of the ET 200 solar collector 'with single glazing'. The same result is found for triple and quadruple glazing (see Fig. 8). In fact, double glazing decreases the efficiency of the solar collector with 15%. This efficiency is decreased by 29,95% for triple glazing, and by 45,96% for quadruple glazing. From the results obtained, the following mathematical relationship that connects the efficiency of the solar collector to the number of glass panes (ng) added can be proposed as:

$$\eta = -8{,}04 \times n_g + 60{,}77 \quad (9)$$

With:
η : Solar thermal collector efficiency in %;
n_g : Number of glass panes added.

This correlation has a determination coefficient (R^2) of 0.9997.

The efficiency of the solar collector decreased, following a linear relation, with the number of glass panes added. In the experimental conditions cited above, the addition of commercial glass panes acts as a resistance to the spread of the energy transmitted by the halogen lamp, this effect reduces the performance of the solar collector instead of improving it. It is recommended to make a numerical study of this experimental investigation to better understand thermal exchanges taking place in the formed sandwiches.

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